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# Including People with Impairments from the Start: External Communication of Autonomous Vehicles

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**Abstract**

People with impairments are among the most vulnerable road users in traffic with significantly higher risk of accidents. Upcoming autonomous vehicles are expected to reduce this but demand some form of external communication to be able to signal their intent or other information to pedestrians. Recent research around the design of vehicle-pedestrian communication focuses strongly on concepts for a non-disabled adult population (e.g. visual cues). This work conducted a current literature review of existing concepts (2014-2019) for vehicle-pedestrian communication (29 publications) and evaluated each according to guidelines of universal design and people with disabilities in mind. Our results uncover shortcomings of the proposed concepts (e.g. over 65% rely solely on visual feedback) and combine these insights with a first impressions of those affected (interview with two visually impaired users).

**Author Keywords**

Self-driving vehicles; Autonomous vehicles; impaired pedestrians; external communication; intention communication; interface design; inclusive design research; accessibility.

**CCS Concepts**

•Human-centered computing → Accessibility;

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©2019 Copyright is held by the owner/author(s).  
ACM ISBN 978-1-4503-6920-6/19/09.  
<https://doi.org/10.1145/3349263.3351521>

## Universal Design

Universal Design [10] defines a set of 7 principles trying to help in the process of designing and evaluating environments and products in a way that they may be accessed, understood and used to the greatest possible extent, in the most independent and natural manner possible, in the widest possible range of situations and without the need for adaptation, modification, assistive devices or specialized solutions, by any persons of any age or size or having any particular physical, sensory, mental health or intellectual ability or disability [33].

## Introduction

Autonomous vehicles (AVs) are expected to change traffic systems radically. AVs are believed to increase safety and facilitate mobility [18]. However, many more aspects will change with the introduction of AVs. Interpersonal communication for situations, in which people today rely on eye-contact or gestures will vanish, as the vehicle can operate autonomously without a human driver. Recent research projects aim to overcome these upcoming challenges through external communication modalities such as displays, LED strips, movement patterns, auditory or tactile cues [6, 13, 16, 20, 26, 27, 29]. Children are recently started to be included in the evaluation and the design [8, 12]. However, most of the research projects focus mainly on middle aged non-disabled people and thereby exclude a majority of the population with disabilities (e.g. currently exist around 217 million people with moderate to severe vision impairment, 36 million people are blind [5] and 466 million people have disabling hearing loss<sup>1</sup>). One possible approach already suggested by some researchers [2, 13, 20, 29], is applying design principles from universal design [10] to create concepts for external communication that target a larger set of the pedestrian population including people with disabilities. To get a better understanding of the requirements and design challenges, we analyze existing work on external communication with special regard to the universal design principles and point to open research gaps.

## Related Work

*Vehicle sounds.* With the emergence of hybrid and electric vehicles, vehicles become much more quiet. Robart and Rosenblum [35] showed that this leads to a much later localization of the vehicle both for sighted as well as for blind participants.

<sup>1</sup><https://www.who.int/news-room/fact-sheets/detail/blindness-and-visual-impairment>, Accessed: 07-06-2019

The European Union has therefore declared an Acoustic Vehicle Alerting System (AVAS) [1] mandatory for electric and hybrid vehicles from 2021. Research was undergone to find possible solutions. Wolgater et al. [40] found that simulating the noise of an actual engine was preferred. Fleury et al. report that these sounds improve detectability and pitch variation and frequency modulation make them more effective [19].

*Coping strategies.* Besides using “traditional” aids such as hearing aids, canes or guide dogs, people with impairments have developed specialized coping strategies for navigation. Wiener and Lawson found that visually impaired persons use traffic sounds to make crossing decisions [39]. People with impairments also use technological aids such as GPS based navigation systems to reach their destination faster [34] and with less errors or halts [24]. Commercial navigation aids specifically tailored for their needs have emerged, e.g. BlindSquare<sup>2</sup>.

## Analysis of External Communication Designs

*Data collection.* Relevant publications in the field of external communication are spread over various journals and conferences. Therefore, the publication databases ScienceDirect (SD) and Google Scholar (GS) were screened. A time frame of five years (2014-2019) was defined as the field of external communication grew significantly in the last years [2].

*Search procedure.* In both databases, the terms *external communication/features* and *autonomous vehicle* were combined. Additionally, the term *pedestrian* was used (search query: (External Communication OR Features) AND (autonomous vehicle) AND pedestrian). In total 433 publications were found (ScD=384, GS=49).

*Screening criteria.* Four criteria were defined to narrow the search. The papers had to be about (1) AVs intended for

<sup>2</sup><http://www.blindsquare.com/>, Accessed: 07-06-2019

### Evaluation criteria

Based on the following principles of universal design [10].

- [10] Principle (1a): Provide the same means of use for all users: identical whenever possible, equivalent when not
- [10] Principle (1d): Make the design appealing to all users
- [10] Principle (3c): Accommodate a wide range of literacy and language skills
- [10] Principle (4a): Use different modes (pictorial, verbal, tactile) for redundant presentation of essential information
- [10] Principle (4d): Provide compatibility with a variety of techniques or devices used by people with sensory limitations
- [10] Principle (7a): Provide a clear line of sight to important elements for any seated or standing user

Principle 4a		4a	7a	4d	4c
used modalities	# publications	# essential info in all modalities	# applicable for seated users	# including techniques or devices used	# literacy + language independent
visual only	19 [2, 3, 6, 7, 8, 9, 11, 12, 15, 21, 25, 26, 27, 32, 37, 38, 41, 42, 43]	19 (100%)	7 (41%)	0 (0%)	8 (42%)
visual + auditory	7 [4, 13, 14, 20, 22, 30, 31]	3 (43%)	7 (100%)	0 (0%)	4 (57%)
visual + tactile	1 [23]	0 (0%)	1 (100%)	1 (100%)	1 (100%)
visual + auditory + tactile	2 [28, 29]	0 (0%)	2 (100%)	2 (100%)	2 (100%)
combined	<b>29</b>	22 (76%)	17 (58%)	3 (10%)	15 (52%)

**Table 1:** Categorization of publications on external communication of AVs regarding their used modality

streets (no water or air based vehicles, e.g. [36]). Additionally, (2) external communication to pedestrians had to be investigated, not, e.g. communication to other vehicles. The publications included for analysis had to be (3) original full papers or Work in Progress (due to the novelty of the field) and had to be (4) written in English or German. If the paper had references that matched the 4 criteria, that paper was also added. Additionally, researchgate.net was screened for all first authors that had were previously found. The screening was performed by the first author. This resulted in a sample of **29** publications.

*Evaluation criteria.* Some of the universal design principles [10] were used for the evaluation of the design concepts (see sidebar). They were chosen with the automotive context in mind.

#### Findings from Literature Survey

The overview given in Table 1 shows that most of the research aims at using visual cues (19/29) to enable external communication of AVs. While this seems a valid approach for the sighted population, there are obvious drawbacks for the visually impaired as well as for distracted persons. We have also

looked at the applicability of the designs for seated users, e.g. people in wheelchairs. The designs were considered to be applicable if the visual cues (displays, LED strips) were located at the top or the center of the vehicle. Projections were also seen as applicable. Visual cues at the bottom of the vehicle were rated as non-applicable because there could be gaze-blocking objects at the curb of the street (high grass, rails). Only 7/19 (41%) were applicable for seated users using these criteria. Several publications claim that *text* is the least ambiguous (visual) modality to convey information [6, 13, 21]. This is, however, contradictory to principle 3c, accommodating for a wide range of literacy and language skills, as it excludes the illiterate as well as foreigners and children.

7 publications investigated visual and auditory (or acoustic) designs. While only 3 (43%) of the publications provided the same essential information in both modalities helping visual impaired, the auditory aspect helps seated users. Language and literacy independence was only given in 4/7 cases as text was used both in the visual as well as in the auditory design.

### Themes discussed with two visually impaired participants

- challenges and coping strategies facing road traffic today
- potential future problems and their views on them (electric and hybrid cars, AVAS)
- presentation of various concepts from literature and their view on them

Only one publication combined visual and tactile (or haptic) cues. These cues were realized in a smartphone app by warning the user of a potential accident [23]. This could work well for seated users with various impairments and is an approach that includes a device often used by people with impairments. It was rated language and literacy independent as the app could be used with one's own preferences (language).

Mahadevan et al. combined three modalities (visual, auditory and tactile) [28, 29]. For this, they used displays, LED strips, a speaker, printed hands as well as smartphones. They did not systematically try every combination of these devices, which is why the essential information was not always conveyed in all modalities used. The proposed designs did include techniques or devices used by people with impairments, were (partly) language and literacy independent (rated as "yes" as most cues were independent). The designs were appropriate for seated users. They [29] mention that it has to be evaluated how many cues are too many to avoid information overload [17].

#### *General Considerations*

The literature review in condensed form (see Table 1) shows that while many designs for external communication of AVs have been proposed with visual cues, other modalities have been widely avoided. The analysis also shows that many universal design principles have not been followed (**none** of the proposed designs fulfill all criteria). To be able to truly propose a universal design, it seems necessary to include people with impairments in the design process. 9 out of 29 (31%) publications actually do mention *accessibility* or *impairment* but none of the work explicitly addresses this audience.

### Including People with Impairments

We have contacted several supra-regional groups of visually impaired persons. Several groups have agreed to collaborate with us to address the problems and find potential solutions.

A first telephone conference with two representatives was held. After giving their consent, the conference was recorded. The first author created a transcript of the phone call and conducted a first thematic analysis about the topics of interest brought up by the two visually impaired participants. The broad topics are shown in the sidebar on page 4. The participants emphasize the need to be included in the design of such external communication tailored to their special needs. They agreed with the findings of Wolgater et al. [40] that they would prefer actual engine sounds. The participants have therefore agreed to continue to work with us, to aid us in understanding their situation and to evaluate other approaches. Telephone conferences as well as focus groups will be held in June, July and August 2019.

### Discussion & Future Work

This work has analyzed 29 publications in the field of external communication of AVs with regard to the universal design principles. The overview has shown that several modalities to convey information are not evaluated sufficiently. It has also shown that the special needs of people with impairments are mostly unmet in the proposed designs. We therefore propose to include people with impairments in the design and evaluation process. In the future we plan to extend this first analysis to a more detailed evaluation of currently existing concepts including different populations with disabilities in the design process.

### Acknowledgements

The authors want to thank all telephone conference participants. This work was conducted within the project Intuitiver funded by the Ministry of Science, Research and the Arts of the State of Baden-Württemberg. The authors are responsible for the content of this publication.

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